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TITLE: Lumbar Spine Musculoskeletal Physiology and Biomechanics During Simulated Military Operations

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13. SUPPLEMENTARY NOTES

14. ABSTRACT
This study evaluated the relationship between 3D geometry of the lumbar spine, under different loading conditions and positions, and the pathophysiology of the intervertebral disc and lumbar trunk muscles. 43 Marines were scanned using upright MRI in operationally relevant loading conditions with minimum load, 39 of these Marines were also scanned in a high-resolution MRI scanner to muscle and disc pathophysiological assessment. Significant decreases in lumbar lordosis were found through all levels except L1-L2 when sitting. When prone on elbows, the only increase in lumbar lordosis was found at L5-S1. A caudal increase in fat fraction of the multifidus was observed, with no significant increase in the erector spine. No significant correlations were found between disc injury and muscle pathophysiology.

15. SUBJECT TERMS
Spine, Lumbar, Kinematics, Muscle Architecture, Low Back Pain, Position

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1. **INTRODUCTION:** The weights of loads carried into battle pose an injury and performance problem for the US Marines. Marine Corps assault loads range from 44kg for the rifleman to 61kg for the squad leader. These are well in excess of the recommended assault load of 22.7kg; 30% of body weight. Two things are clear: (1) Marines routinely carry more weight than the recommended limit, and (2) the Veterans Administration shows an increasing trend in disabilities related to lower back injury as a result of carrying excessive loads in operational environments. We have implemented new MRI technologies enabling quantification of lumbar spine kinematics under simulated march conditions. From these investigations, we have observed a large number (37.5%) of Marines with some evidence of disc pathology. However, it is unclear if these disc changes, or the expected concomitant muscle changes, are related to kinematic changes in the lumbar spine. Further, it is not known whether pre-existing disc pathology predicts future injury and service life in U.S. Marines. Our central hypothesis is that lumbar disc and muscle degeneration alters the kinematic response of the lumbar spine to functional positions and loads, predisposing individuals to injury.
2. **KEYWORDS:** Spine, Lumbar, Kinematics, Muscle Architecture, Low Back Pain, Position
3. **ACCOMPLISHMENTS:**

- **What were the major goals of the project?**
  - Major Goal 1: To compare lumbar spine kinematics in simulated operational conditions in Marines with measurable lumbar disc pathology
    - Task 1-Approved IRB Protocols
      - Local IRB Approvals
        - Due: 01 August 2013
        - Completed: 100%
      - HRPO Approvals
        - Due: 01 August 2013
        - Completed: 100%
    - Task 2-Subject battalions identified and coordinated
      - Subjects 1-33 recruited, consented and scheduled
        - Due: 01 February 2014
        - Completed: 100%
      - Subjects 34-66 recruited, consented and scheduled
        - Due: 01 August 2014
        - Completed: 81%
      - Subjects 67-100 recruited, consented and scheduled
        - Due: 01 Jan 2015
        - Completed: 0%
    - Task 3-Data Collection/Analysis

        - Vertical data acquisition
            - Due: 01 December 2015
            - Completed: 57%
        - Vertical data analysis
            - Due: 01 February 2016
            - Completed: 57%
- Major Goal 2: To quantify changes in lumbar spine muscle architecture in Marines with measurable lumbar disc pathology.
    - Task 1-Approved IRB Protocols
        - Local IRB Approvals
            - Due: 01 August 2013
            - Completed: 100%
        - HRPO Approvals
            - Due: 01 August 2013
            - Completed: 100%
    - Task 2-Subject battalions identified and coordinated
        - Subjects 1-33 recruited, consented and scheduled
            - Due: 01 February 2014
            - Completed: 100%
        - Subjects 34-66 recruited, consented and scheduled
            - Due: 01 August 2014
            - Completed: 18%
        - Subjects 67-100 recruited, consented and scheduled
            - Due: 01 Jan 2015
            - Completed: 0%
    - Task 3-Data Collection/Analysis
        - Supine data acquisition
            - Due: 01 December 2015
            - Completed: 39%
        - Supine data analysis
            - Due: 01 February 2016
            - Completed: 39%

- **What was accomplished under these goals?**
- 43 Marines (mean age = 26.8 ± 6.4 years, height = 1.78 ± 0.07 meters, weight = 82.04 ± 9.85 kg., BMI = 25.90 ± 2.86kg/m^2) were scanned in an upright MRI machine in their normal standing position (StU;

no load), standing with body armor (11.3 kg) (StL), sitting with body armor (SiL), and prone on elbows with body armor (PL) positions. Digital seed points were manually placed on the corners and the posterior elements of each vertebra using OsiriX. The location of the seed points were imported into Matlab and used to define an endplate-based joint coordinate system applied to the superior and inferior endplate of each vertebra. This method is detailed in Berry DB et al., "An endplate-based joint coordinate system for measuring kinematics in normal and abnormally-shaped lumbar vertebrae." *J Appl Biomech*; 31(6):499-503. 2015.

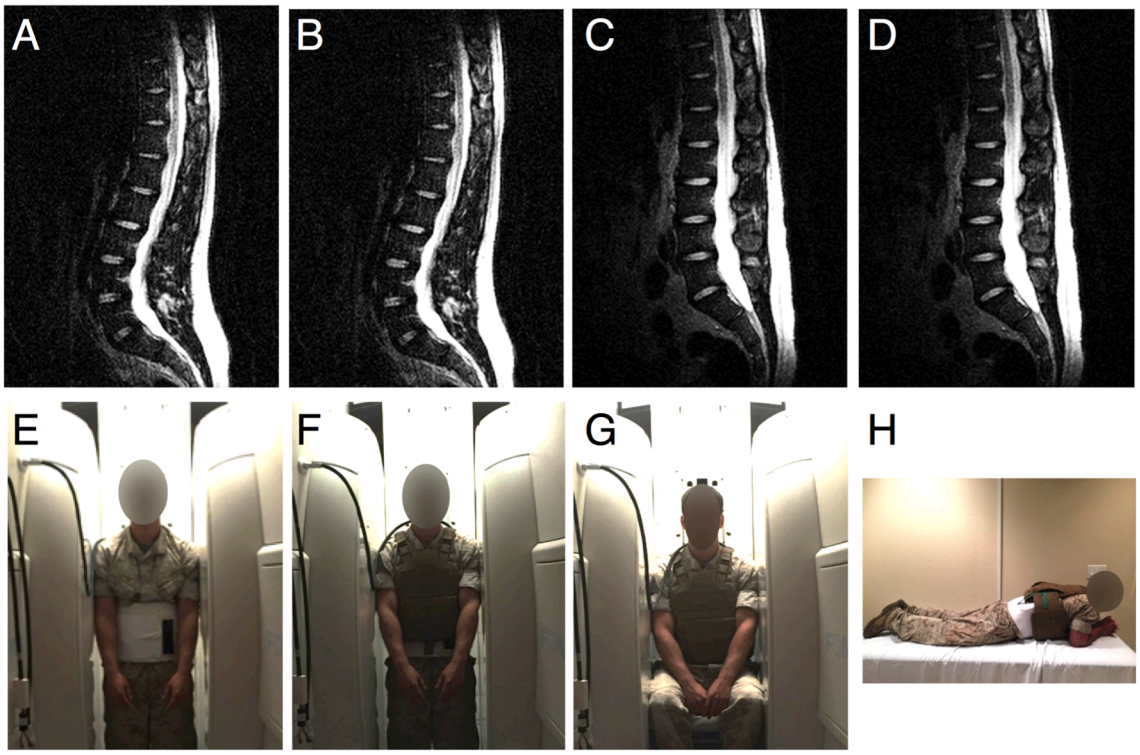


Figure 1: T2-weighted mid-sagittal magnetic resonance images of the lumbar spine (top) and photographs of Marines in the MRI scanner (bottom). Volunteers were scanned standing unloaded (A, E), standing with body armor (B, F), sitting with body armor (C, G) and prone on elbows with body armor (D, H).

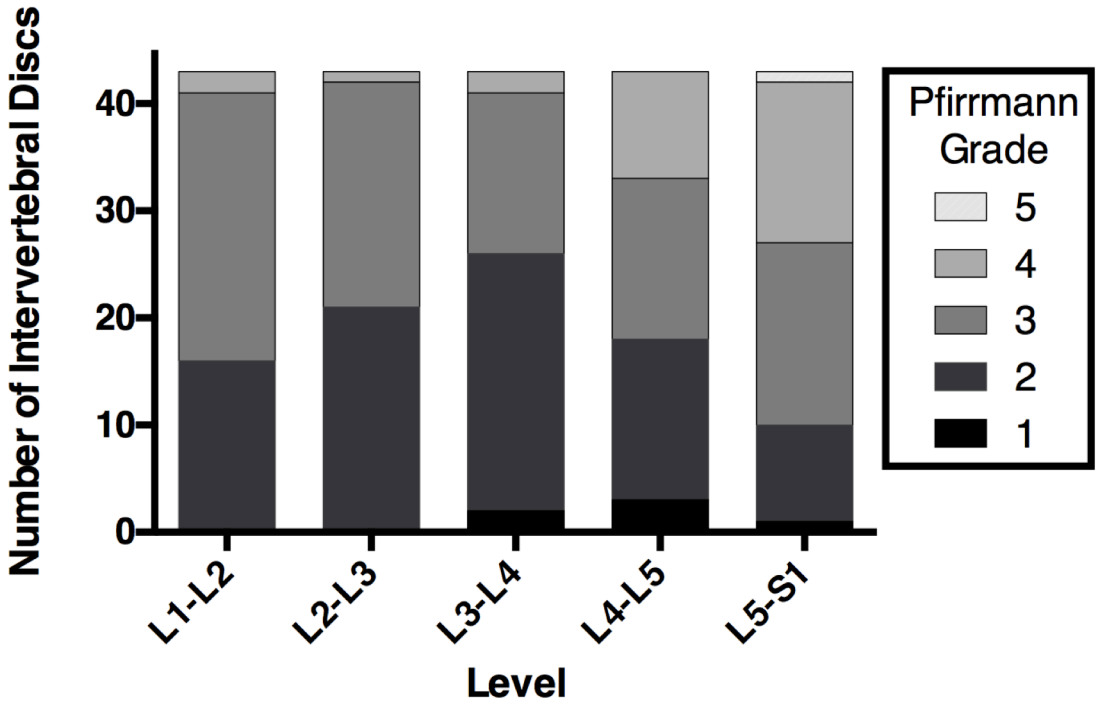


Figure 2: Distribution of Pfirrmann graded intervertebral discs by level. Disc degeneration increases caudally through the lumbar spine. 33/43 (77%) of Marines spines were classified as degenerated based on having a Pfirrmann grade >2 at L5-S1.

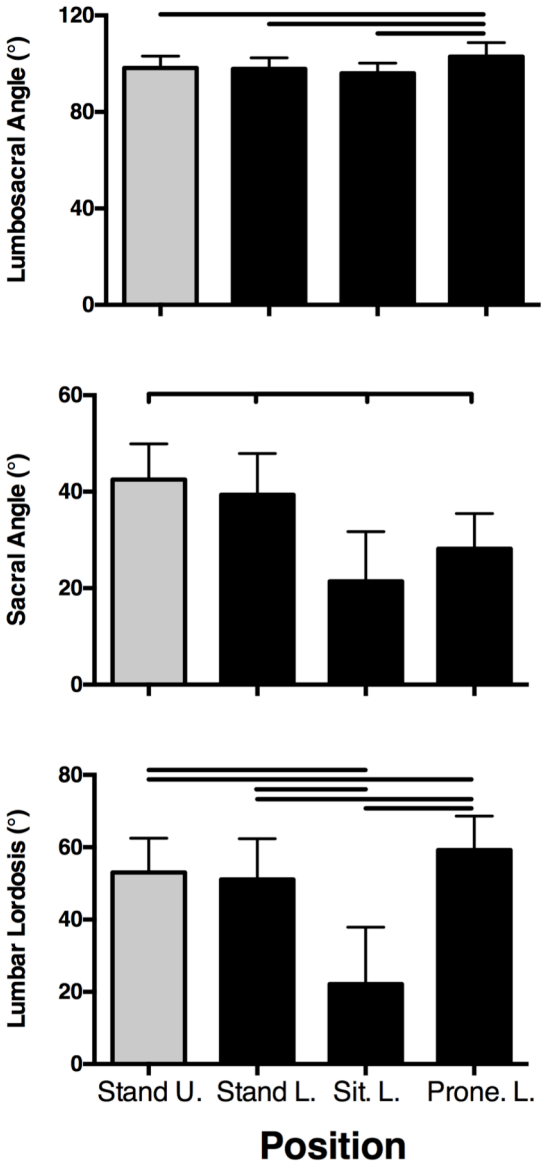


Figure 3: Global measures of lumbar spine posture. Top: angle with respect to horizontal. Middle: Sacral Slope. Bottom: Cobb angle. Statistical significant difference between measurements ($p>0.05$) indicated by line. Marines with disc degeneration at L5-S1 were found to have less whole lumbar range of motion, (difference between Cobb angle sitting and prone on elbows) then healthy controls (9°).

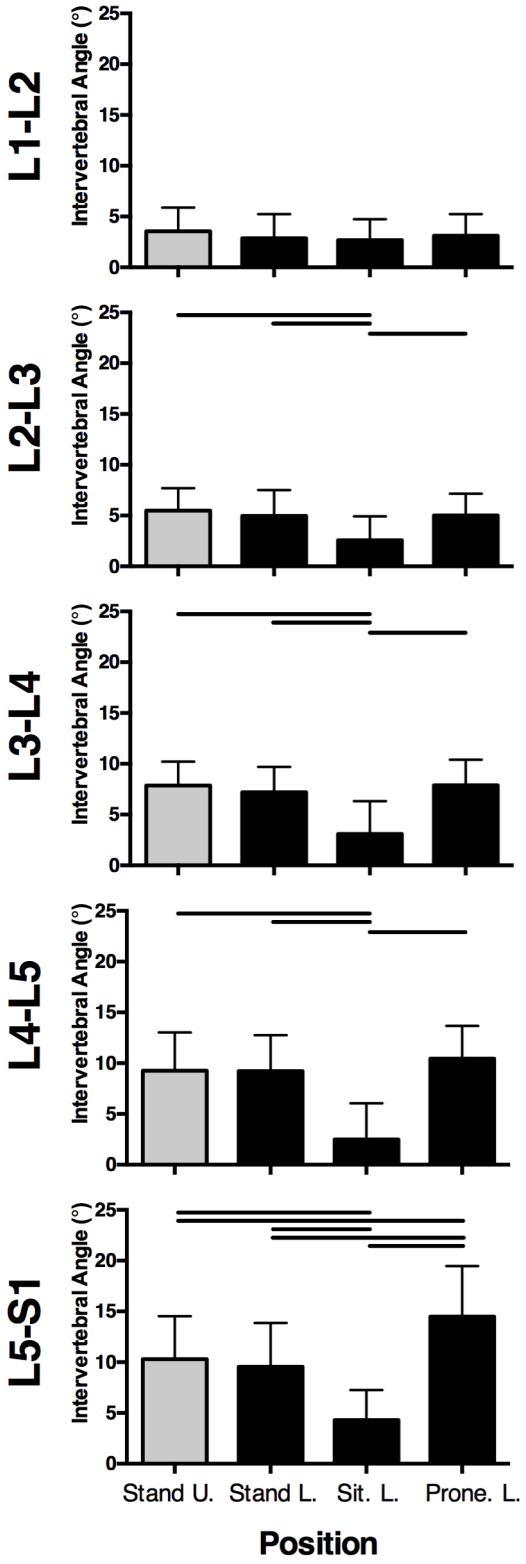


Figure 4: Local measures of lumbar spine posture. Intervertebral angles from L1-L2 (top) to L5-S1 (bottom) are shown. Statistical significant difference between measurements ($p>0.05$) indicated by line.

- Supine 3T MRI images were acquired from 39 Marines. Psoas, Quadratus Laborum and Erector Spinae muscles, and the Intervertebral disc were manually segmented using OsiriX. Physiologic measurements were made based on segmented tissues and structural anatomic scans. Average T2 value of the intervertebral disc was proportional to Pfirrmann grade. No significant differences were found between volume, fat fraction, T2, or DTI in any of the muscles in subjects with disc degeneration. A postitive correlation was found between subjects height and weight compared to muscle volume.

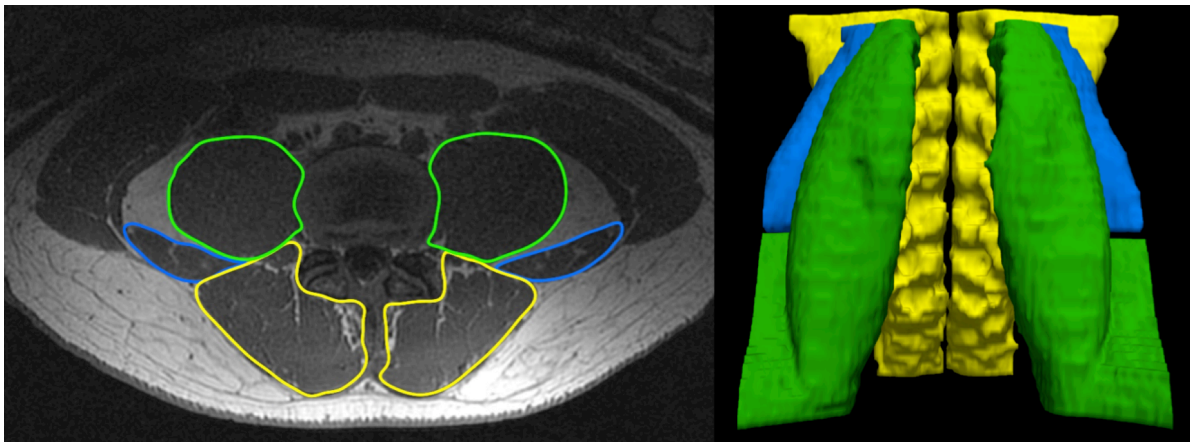


Figure 5. (Left) Axial anatomical image of paraspinal and trunk muscles delineated per manual segmentation, and (right) Anterior view of three-dimensional reconstruction of paraspinal and trunk muscles: ES+M (yellow), PS (green), and QL (blue).

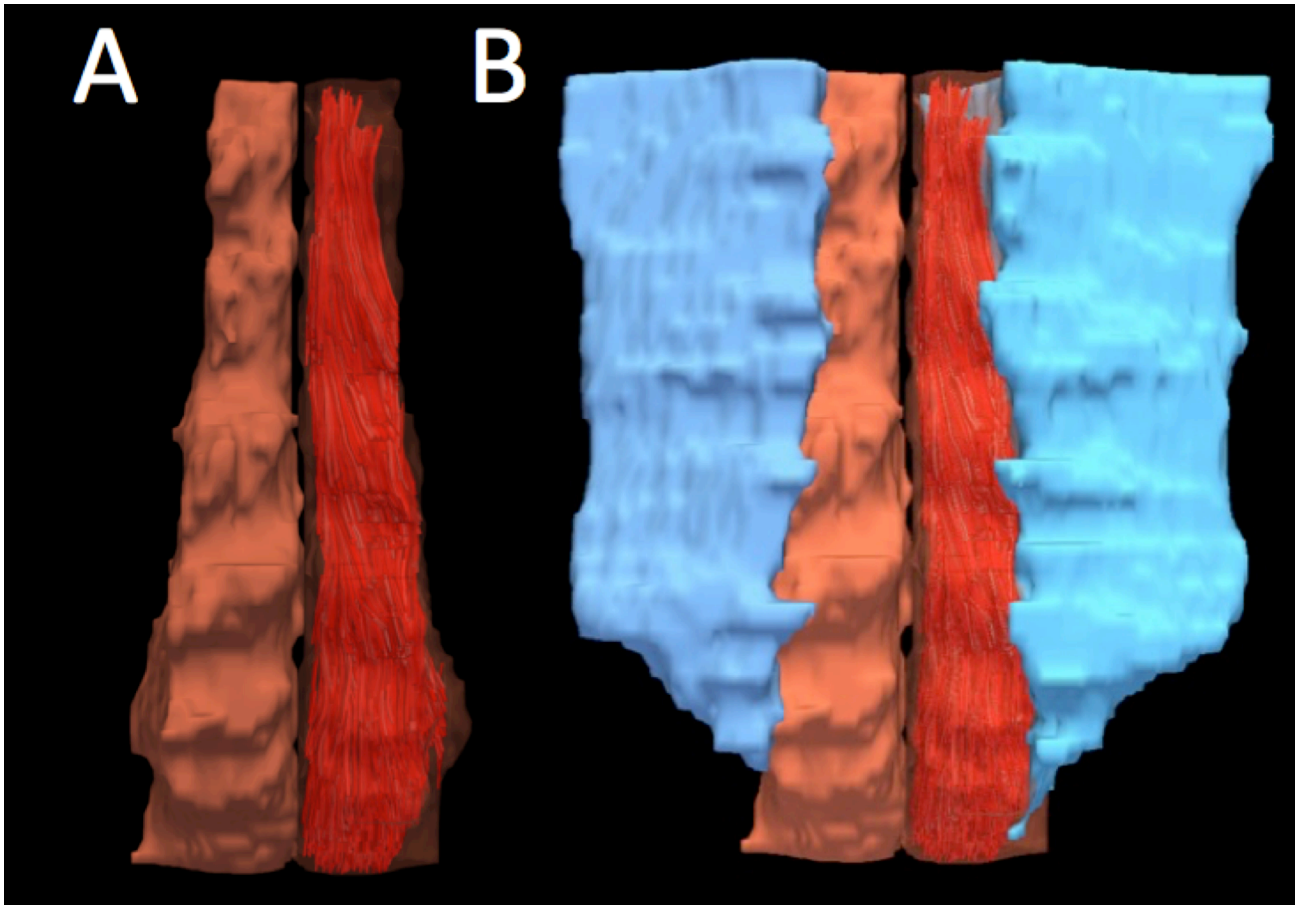


Figure 6. Tractography of multifidus muscle from diffusion tensor imaging (A), shown in red. Erector spinae volumes are shown in blue (B)

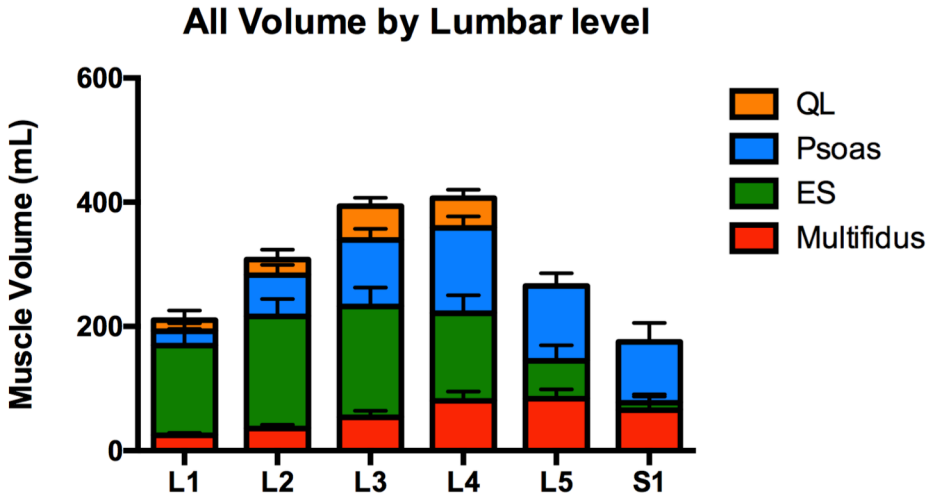


Figure 7: Volume of the lumbar trunk muscles at each vertebral level. The volume of the erector spinae was greater at upper lumbar levels (L1-L3), and the volume of the multifidus was greatest in the lower lumbar spine (L4-S1). Psoas and quadratus lumborum volume increase caudally.

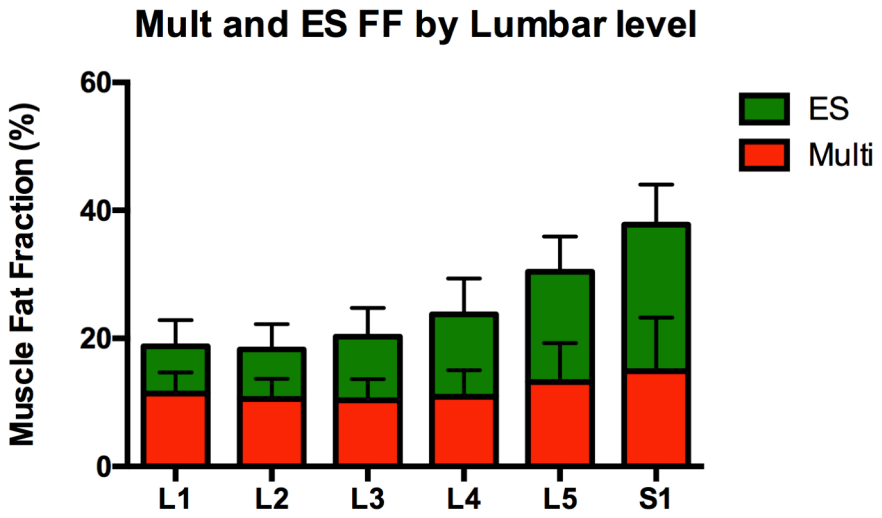


Figure 8: Fat fraction of the erector spinae and multifidus muscles at each vertebral level. The erector spinae has elevated fat fraction compared to the multifidus. Erector Spine fat fraction increases caudally while multifidus fat fraction remains the same across lumbar levels.

- 12 Marines (mean±SD age, 23.41±4.71 years; age range 19–35 years; height, 177.8±5.41 cm; weight, 76.77±11.32 kg; body mass index, 24.15±2.19 kg/m^2) were scanned in an upright MRI machine standing unloaded and while carrying 22, 33 and 45kg of load distributed both 50%-50% and 20%-80% anteriorly and posteriorly (AP), respectively. Postural measurements were made as described above.

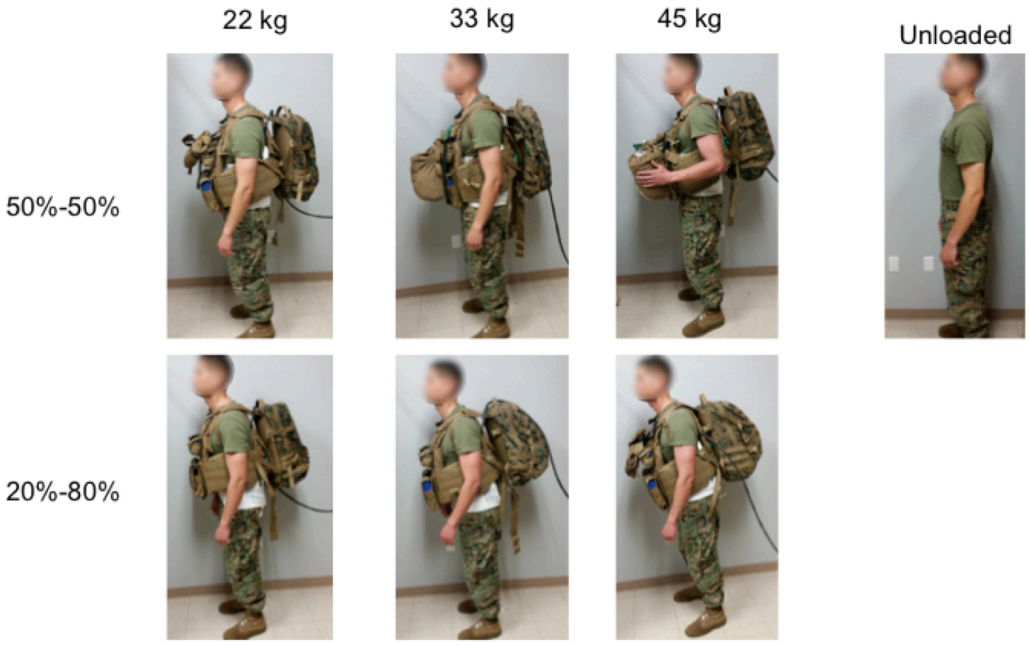


Figure 9. Photographs of the load distribution system used for this study. The black cable seen in the pictures is from the MRI coil.

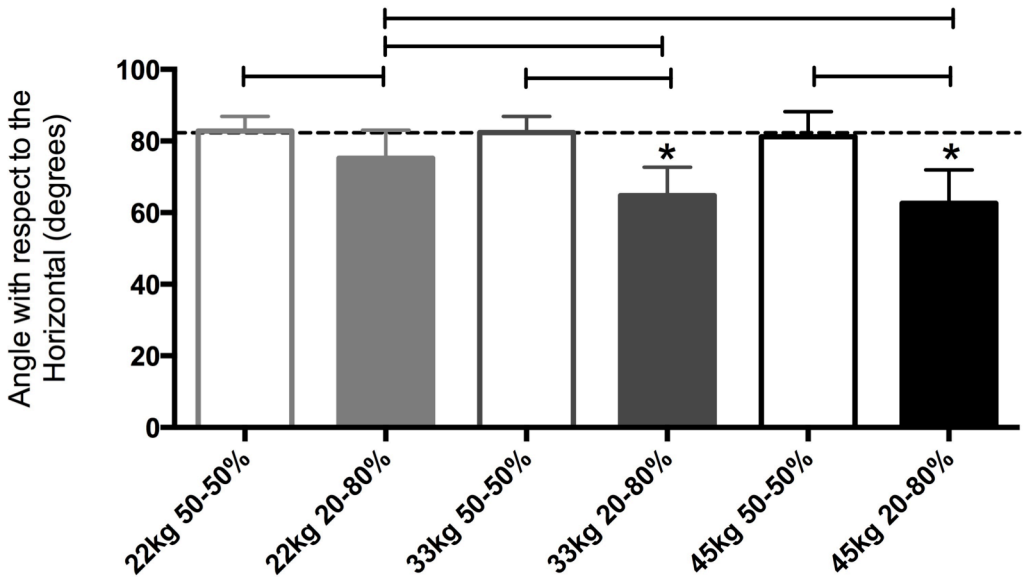


Figure 10: Lumbar spine flexion results for loads carried with equal anterior-posterior distribution (clear bars) and with posterior bias (solid bars) for 22kg (clear grey), 33kg (dark grey) and 45kg (black). The dashed line represents trunk flexion when standing without external load. Solid horizontal bars represent significant differences ($p<0.05$) between load magnitudes and configurations. Asterisks represent significant differences when compared to the standing unloaded position. . A decrease in angle with respect to the horizontal indicates a subject is leaning forward. A significant effect of load and distribution was found. When load is evenly distributed, no change in forward leaning was observed. When load is distributed 20/80 anterior/posterior, subjects will lean more forward.

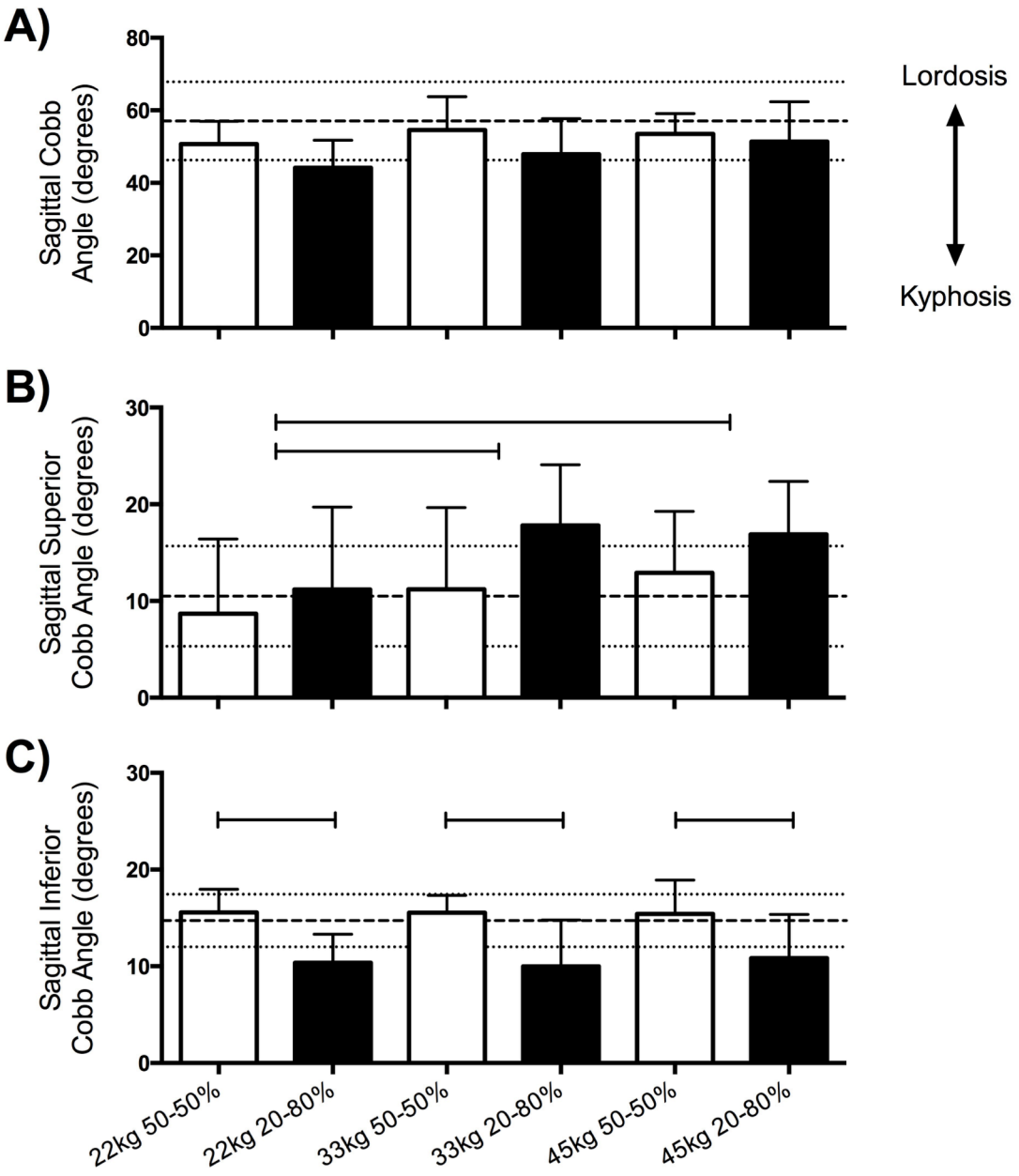


Figure 11. Cobb angle was measured in each position to assess lumbar lordosis. A.) Sagittal Cobb angle is measured from the superior endplate of L1 to the superior endplate of S1 B.) Sagittal Superior Cobb angle is measured from the superior endplate of L1 to the inferior endplate of L3 C.) Sagittal Inferior Cobb angle is measured from the superior endplate of L4 to the superior endplate of S1. As load increases, the superior lumbar spine increases lordosis when load is distributed 20/80. There is a decrease in lordosis in the inferior lumbar spine when load is distributed 20/80.

- **What opportunities for training and professional development has the project provided?**
  - Nothing to report
- **How were the results disseminated to communities of interest?**
  - Nothing to report

- **What do you plan to do during the next reporting period to accomplish the goals?**
  - During the next reporting period, we intend on completing data analysis for supine MRI measures and preparing manuscripts on the following topics: 1. Kinematics of the lumbar spine of active duty Marines in simulated operational positions, 2. Pathophysiology assessed by MRI of the lumbar spine muscles in active duty Marines, 3. Technical note: Diffusion Tensor Imaging in the Lumbar Spine, diffusion measurements and tractography, 4. Comparison between lumbar spine kinematics and muscle physiology in Active Duty Marines.

4. **IMPACT:**

- **What was the impact on the development of the principal discipline(s) of the project?**
  - The results of this study may inform a set of load carriage guidelines to be put in place, through changes in training practices, gear design and/or implementation of exercises to strengthen the musculature of the spine. Additionally, the results of this study will allow researchers to better relate the complex 3D geometry of the lumbar spine in subjects with different levels of lumbar disc and degeneration and muscle health. The role of idiopathic lumbar back pain on lumbar spine kinematics will also allow us to investigate differences in the shape of the lumbar spine between a wide range of positions.
- **What was the impact on other disciplines?**
  - Nothing to report
- **What was the impact on technology transfer?**
  - Nothing to report
- **What was the impact on society beyond science and technology?**
  - The broad impact is that the load recommendations determined from this study can be applied to anyone who works with their spine under awkward or loaded positions.

5. **CHANGES/PROBLEMS:**

- **Changes in approach and reasons for change**
  - Nothing to report
- **Actual or anticipated problems or delays and actions or plans to resolve them**
- One adverse event has occurred: one subject experiences peripheral nerve stimulation and claustrophobia in the supine scanner (19/02/2014). He was immediately removed from the scanner and calmed down. For this subject, kinematic but not anatomical supine data was acquired.
- **Changes that had a significant impact on expenditures**
  - Nothing to report
- **Significant changes in use or care of human subjects, vertebrate animals, biohazards, and/or select agents**
  - Nothing to report
- **Significant changes in use or care of human subjects**
  - Nothing to report

- **Significant changes in use or care of vertebrate animals.**
  - Nothing to report
- **Significant changes in use of biohazards and/or select agents**
  - Nothing to report

6. **PRODUCTS:**

- **Publications, conference papers, and presentations**
- **Journal publications.**
  - Berry DB, Rodriguez-Soto AE, Tokunaga JR, Gombatto SP, Ward SR., "An endplate-based joint coordinate system for measuring kinematics in normal and abnormally-shaped lumbar vertebrae." *J Appl Biomech*; 31(6):499-503. 2015.
  - Rodriguez-Soto AE, Berry DB, Palombo L, Kelly KR, Ward SR. "The effect of load magnitude and distribution on lumbar spine posture in active-duty Marines. *Accepted. Spine.*
- **Books or other non-periodical, one-time publications.**
  - Nothing to report
- **Other publications, conference papers, and presentations.**
  - Berry DB, Rodriguez-Soto AE, Gombatto SP, Jaworski R, Kelly KR, Ward SR. "Lumbar spine postures in Marines during simulated operational consitions." Military Health System Research Symposium, Ft. Lauderdale, 2014. *Honorable Mention.*
  - Berry DB, Rodriguez-Soto AE, Tokunaga JR, Gombatto SP, Ward SR. "An endplate-based joint coordinate system for measuring kinematics in normal and abnormally shaped lumbar vertebrae." Orthopaedic Research Society, Las Vegas. 2015.
  - Rodriguez-Soto AE, Stambaugh JR, Su J, Berry DB, Gombatto SP, Kelly KR, Ward SR. "Spinal muscle quality changes in physically active individuals with disc degeneration" Orthopaedic research society, Las Vegas, 2015.
  - Rodriguez-Soto AE, Berry DB, Palombo L, Valaik E, Kelly KR, Ward SR. "The effect of load magnitude and distribution on lumbar spine posture in active-duty Marines." American Society of Biomechanics, Cincinnati, 2015.
- **Website(s) or other Internet site(s)**
  - Nothing to report
- **Technologies or techniques**
  - Nothing to report
- **Inventions, patent applications, and/or licenses**
  - Nothing to report
- **Other Products**
  - Nothing to report.

7. **PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS**

- **What individuals have worked on the project?**

Name:	David Berry
Project Role:	Graduate Student
Researcher Identifier (e.g. ORCID ID):	0000-0001-8275-8322
Nearest person month worked:	*12*
Contribution to Project:	*Mr. Berry has participated in upright MRI data collection, data analysis and interpretation of results*
Funding Support:	

Name:	Ana Rodriguez-Soto
Project Role:	Graduate Student
Researcher Identifier (e.g. ORCID ID):	0000-0002-9544-547X
Nearest person month worked:	*12*
Contribution to Project:	*Ms. Rodriguez-Soto has participated in supine data collection, data analysis and interpretation of results*
Funding Support:	UC MEXUS-CONACYTDoctoral Fellowship Cohort2010

Name:	Dr. Sara Gombatto PT, PhD
Project Role:	Project Advisor
Researcher Identifier (e.g. ORCID ID):	0000-0002-8284-4789
Nearest person month worked:	*3*
Contribution to Project:	*Dr. Gombatto has assisted with upright MRI data collection and interpretation of results*
Funding Support:	University Grants Program, San Diego State
Name:	Dr. Karen Kelly PT, PhD
Project Role:	Primary Investigator
Researcher Identifier (e.g. ORCID ID):	0000-0001-8003-6123
Nearest person month worked:	*6*
Contribution to Project:	*Dr. Kelly has assisted with subject recruitment, subject scheduling, subject consent, and interpretation of results*
Funding Support:	Award #new award 03/01/2015-09/30/2016 2.4 calendar Office of Navy Research Program Evaluation of SEAL Delivery Vehicles Unit Level Training The primary aim of this project is to describe the physiological, physical, cognitive and sleep changes that occur during unit level training in a specialized military operational specialty. Award #N1421 10/01/2014-09/30/2015 2.4 calendar Army Special Operation Command Validating Gender-Neutral Standards for Army Special Forces (SFAS) and Ranger (RASP) Selection The primary aims of this project are (1) To determine whether the selection criteria for entry into SFAS/RASP training are accurate predictors of success during SFAS/RASP training; and (2) To establish task-dependent selection and training criteria, which could then be viewed as “gender neutral,” thus meeting the directive of the Secretary of Defense.

	Award #N1336 09/01/2013-06/30/2015 9.0 calendar Naval Special Warfare-WARCOM 265,000.00 Validating Gender-Neutral Standards for SEAL and SWCC Selection The primary aims of this project are (1) To determine whether the selection criteria for entry into SEAL/SWCC training are accurate predictors of success during SEAL/SWCC training; and (2) To establish task-dependent selection and training criteria, which could then be viewed as "gender neutral," thus meeting the directive of the Secretary of Defense. Award #N1324 03/01/2013-09/30/2016 0.6 calendar Office of Navy Research Independent Evaluation of the ETOWL software program The Office of Navy Research funded Iowa University to develop a virtual Marine that will predict the effect of load on physiological and biomechanical parameters. This project aims to independently test the developed software using "live" active duty military personnel to determine the accuracy of the software program. Award #N1310 03/01/2013-09/30/2016 2.4 calendar Program Manager-Infantry Combat Equipment Personal Protection Equipment Development The purpose of this project is to test a prototype of a novel plate carrier system against the existing plate carrier system in a variety of different load conditions as well as in various environments. Award #N1305 02/01/2012-09/30/2015 1.0 calendar Congressionally Directed Medical Research Programs Lumbar Spine Musculoskeletal Physiology and Biomechanics During Simulated Military Operations The purpose of this project is to determine if lumbar disc and muscle degeneration alters the kinematics response of the lumbar spine to functional positions and loads, predisposing individuals to injury. Award # N1301 10/01/2012-09/30/2015 0.6 calendar

	Naval Special Warfare-Center Evaluation of VASPER The purpose of this project is to evaluate whether the VASPER system can be used as an adjunctive mode of training in U.S. Navy SEALS. Award # 21A839 03/01/2012-12/30/2015 1.0 calendar Naval Special Warfare-Group 1 Androgen Deficiency in Navy SEALS The purpose of this project is to identify risk factors associated with hormonal imbalance in our elite forces. The study address caloric intake, expenditure, sleep hygiene, alcohol consumption as well as lifestyle choices that may influence hormone production in Navy SEALS. Award # 21A843 09/30/2012-9/30/2015 0.4 calendar Naval Special Warfare-Group 1 Warrior Development The purpose of this project is to identify risk factors associated with decrements in performance and to evaluate means by which to improve the Special Warfighter. Award # N1263 09/30/2012-09/30/2016 0.6 calendar Space and Naval Warfare Systems Command Bureau of Medicine and Surgery Prescriptive Exercise Therapy Program to Reduce Hyper-arousal in Residential Treatment for Active Duty Service Members Diagnosed with Post-Traumatic Stress Disorder To improve the quality of exercise/physical training the service members are receiving while at OASIS, as well as to develop a new exercise program and assist in training the staff at OASIS to maintain the quality of physical training after the project is complete. It is hypothesized that with better exercise and physical training there will be improvements in symptoms of PTSD, better compliance with exercise, increased mood and thus functionality of the persons obtaining treatment at OASIS.

Name:	Dr. Samuel Ward PT, PhD
Project Role:	Primary Investigator
Researcher Identifier (e.g. ORCID ID):	0000-0002-4470-155X
Nearest person month worked:	*6*
Contribution to Project:	Dr. Ward has assisted with project oversight and interpretation of results
Funding Support:	Ongoing Research Support R01 HD073180-01A1 (PI: Ward) 04/01/2013 – 03/31/2018 NIH/NICHD **The Physiological Basis of Rotator Cuff Muscle Rehabilitation** The goal of this project is to elucidate the structural, mechanical, and physiological consequences of tendinopathy-related muscle atrophy and degeneration after rotator cuff tears in humans. Architectural, passive mechanical, and gene expression profiles will be measured and compared amongst patients with different rotator cuff tear severities. 2012-5219 PR120576 (PI: Ward) 09/30/2013 – 09/29/2016 DoD (PRMRP/CDMRP) **Lumbar Spine Musculoskeletal Physiology and Biomechanics During Simulated Military Operations** The goals of this project are to; 1) understand lumbar spine an lumbar disc kinematics during simulated operational conditions, 2) understand the effect of load and body position on spine and disc kinematics when pathology is present, and 3) understand the influence of muscle structure and physiology on lumbar spine kinematics. 2R01HD031476-11A1 (PI: Kaufman [Mayo], Sub CO-PI: Ward) 07/01/2011 - 06/30/2016 NIH/NICHD **Microsensor for Intramuscular Pressure Measurement** The purpose of this grant is to develop a miniature pressure transducer to measure tissue fluid pressure in skeletal muscle and then to determine the effects of muscle architecture, fascia, limb orientation and type of activation on pressure. The study employs the rabbit tibialis anterior muscle model and consists primarily of in situ muscle physiological experimentation combined

	with continuum mechanics modeling. A6239R (PI: Lieber, CO-I: Ward) 10/01/2012-09/30/2016 Veterans Medical Research Foundation **Mechanical Basis for Tensioning Tendon Transfers** The purpose of this proposal is to measure the *in vivo* properties of muscles commonly used in tendon transfer surgery. We propose to develop a new instrument for measuring sarcomere lengths intraoperatively and to assess post-operative function in these patients. 1P30AR061303 (PI: Lieber, Core-Director: Ward) 09/01/2011-08/31/2016 NIH (NIAMS) **San Diego Skeletal Muscle Research Center** The purpose of this Center is to establish a consortium of skeletal muscle scientists between UC San Diego, Sanford-Burham, the Scripps Research Institute, and San Diego State University. The Center provides education, pilot funding, and direct scientific support. R01 AR057836 (PI: Thomopolus/Galatz Wash U, Sub PI: Ward) 09/15/2010 – 06/30/2015 NIH/NIAMS **Rotator Cuff Degeneration and Repair.** The purpose of this study is to measure the passive mechanical and related protein changes in rat skeletal muscle after rotator cuff tears. 2 R24 HD050837 (Co-PI: Lieber, Ward) 09/15/2005 - 07/31/2015 NIH/NICHD **"National Center for Muscle Rehabilitation Research."** The purpose of this grant is to provide a resource to the rehabilitation professionals to perform state-of-the-art muscle experiments. Disciplines include physiology, microscopic imaging, MR imaging and clinical measurements. In addition, the Center provides sabbatical opportunities and pilot project support to rehabilitation professionals interested in skeletal muscle research. 5 R01 AR057393 (Co-PI: Lieber, Ward) 7/01/2010 – 6/30/2015

	NIH/NIAMS **"Muscle Biological and Biomechanical Response in Cerebral Palsy."** The purpose of this proposal is to understand the changes that occur in muscles after contracture formation and to test conservative treatment options. This is due to the large number of children with CP seen in the rehabilitation setting and the number who undergo surgical correction for contracture (making their muscle tissue available) R01 AR057013-01A1 (PI: Ward, Samuel) 07/01/2009 – 06/30/2014 NIH/NIMAS **Muscle Structure, Toxin Dose, and Exercise Affect Botulinum Toxin Efficiency.** The purpose of this grant is to understand the acute and chronic effects of botulinum toxin type A on skeletal muscle structure and function. Experiments include muscle physiology, histology, cellular biology, MRI and bioluminescence measurements.

- **Has there been a change in the active other support of the PD/PI(s) or senior/key personnel since the last reporting period?**
  - Nothing to report
- **What other organizations were involved as partners?**
  - **Organization Name:** San Diego State University
  - **Location of Organization:** San Diego, CA
  - **Partner's contribution to the projec**t
    - **Collaboration**: Sara Gombatto PT, PhD. Provided assistance during data collection and data interpretation

8. **SPECIAL REPORTING REQUIREMENTS**

- **COLLABORATIVE AWARDS:** None
- **QUAD CHARTS:** See attached FY1516_QuadChart_W81XWH-13-2-0043

9. **APPENDICES:**

- Quad Chart: FY1516_QuadChart_W18XWH-13-2-0043.pptx

Lumbar Spine Musculoskeletal Physiology and Biomechanics During Simulated Military Operations

PR120576:
W81XWH-13-2-0043

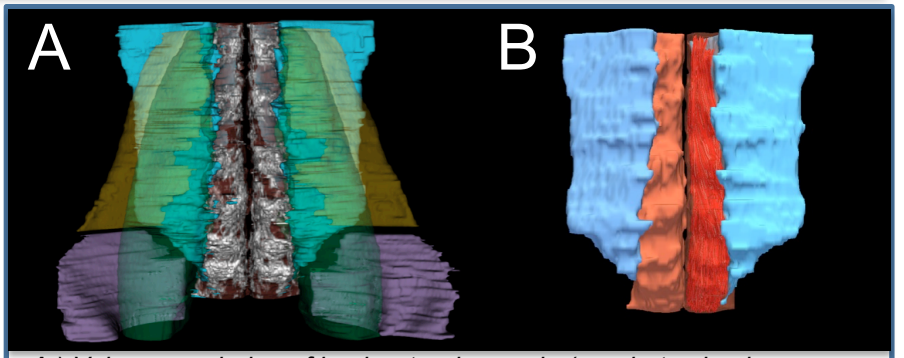
PI: Samuel Ward, Karen Kelly **Org:** UC San Diego, NHRC **Award Amount:** $1,250,000.00

Study/Product Aim(s)

- To compare lumbar spine kinematics in simulated operational conditions in Marines with measureable disc pathology
- To quantify changes in lumbar spine muscle architecture in Marines with measureable lumbar disc pathology

Approach

Each Marine undergoes high-resolution structural and physiological imaging of the lumbar vertebrae and discs in a high strength (3T) supine MRI. Marines then undergo a 3D imaging protocol in an upright, low strength (0.6T) MRI in standing unloaded, standing loaded (25lb body armor), sitting loaded and prone on elbows positions. To investigate the effect of load magnitude and distribution, some Marines were scanned in standing unloaded and standing loaded conditions (6 conditions: 22kg, 33kg, 45kg x 50/50, 20/80 anterior/posterior). Back pain history is recorded for each subject at time of data collection.



A.) Volume rendering of lumbar trunk muscle (quadratus lumborum; yellow; psoas, green; iliacus, purple; erector spinae, blue) with sample fat (white) fraction distribution in the multifidus (red) muscle. B.)Tractography of multifidus muscle from diffusion tensor imaging.

Accomplishment: Kinematic data has been collected and analyzed for 55 subjects, anatomic data has been collected and analyzed for 39 subjects.

Timeline and Cost

Activities CY	13	14	15	16
Subject Battalion Identification and Coordination				
Supine and Vertical MRI Data collection				
Data Analysis				
Dissemination of Findings				
Estimated Budget ($K)	**$168**	**$191**	**$229**	**$80**

Updated: (20160602)

Goals/Milestones

CY13 Goal – Initiate subject recruitment/scanning
☑ Begin acquiring data on minimum 8 subjects
CY14 Goals – Develop measurement tools
☑ Validate tool for measuring kinematics
☑ Diffusion Tensor Calculations
☑Scan >40 subjects
CY15 Goal – Data Analysis
☑Scan remaining subjects
☑Analyze data from 80% of the subjects
CY16 Goal – Disseminate findings
☐ Correlate kinematic physiologic data
☐Disseminate Findings

Comments/Challenges/Issues/Concerns

Nothing to Report

Budget Expenditure to Date

Projected Expenditure: $719,948 total cost (fully expend the award through the NCE period)
Actual Expenditure: $565,656.76 total cost